Fostering Pro-Environmental Attitudes in Future Early Childhood Educators: The Development and Effectiveness of an STSE-Based Training Model

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Abstract
The growing planetary crisis linked to sustainability, viewed within a global context alongside the UN Agenda 2030 Sustainable Development Goals, has increased demands for Education for Sustainable Development and ecological citizenship to be included in teacher preparation, especially at younger grades where values toward the environment are formed. Yet, pre-service early childhood teachers often start in the profession with very few pedagogical models for authentically embedding sustainability within science-themed learning. The present study developed and validated a model for STSE-based environmental education training to enhance pro-environmental attitudes among prospective early childhood teachers. The study was anchored on one of the ten stages of the Research and Development model by Borg and Gall (Yuyun et al., 2025; Nawali et al., 2024; Siantoro et al., 2024; Untoroseto & Triayudi, 2023), which consists of: needs analysis, planning, preliminary product development, expert validation, prototype revision, main field testing, and operational product revision. The product comprised two combined training and training manuals: a scenario book of the STSE training model in early learning experiences, containing science learning and supporting materials. Across the dimensions of usefulness, accuracy, and feasibility of use, the model was validated by three domain experts who represented early childhood education, environmental education, and educational technology. These experts were considered target users, and the validation employed a four-point summated rating scale anchored in R&D conventions (Yuyun et al., 2025; Siantoro et al., 2024). Instrument validation was carried out according to international guidelines for the validation of attitude scales in pre-service teachers (Keleş, 2017; Toro-Troconis et al., 2023). This was supported by corrected item-total correlation analyses, with all 24 items exceeding the conventional >0.300 threshold (Keleş, 2017; Toro-Troconis et al., 2023), and by testing for reliability of subscales with Cronbach's alpha $\alpha = 0.897$ across the groups of five attitude aspects among these same 24 items (lengthy details not reported here). Effectiveness testing used a one-group pretest–posttest quasi-experimental design with 40 fifth-semester undergraduate students from the ECE teacher education program at Universitas Mataram, Indonesia, after they had completed their field practicum (Sidiropoulos, 2018; Khazen et al., 2025). Five university professors, who had different expertise in upper secondary education and training meeting designs, operationalized the STSE syntax of invitation, exploration, discovery/creation (integrative), explanation/problem-solving practices, and action-taking (Bascopé et al., 2019; Rasis et al., 2023; Yıldırım & Sevi, 2016). In accordance with established methodological norms for sustainability education research, the data were analyzed via Kolmogorov–Smirnov normality test and paired-samples t-tests for each of the attitude dimensions (Sidiropoulos, 2018; Hernawan et al., 2022; Sari & Pujiastuti, 2022; Toro-Troconis et al., 2023). Important gains in all four dimensions of attitude (caring for the environment, appreciation of the environment, responsibility toward the environment, and enthusiasm for learning about and protecting the environment) were statistically significant ($p < .001$). The strongest pre-post effect was in the enthusiasm dimension ($t = -7.053$, $p = .000$). The mean effect summed across all dimensions was also significant ($t = -34.374$, $p = .000$). Expert judgment rated the product as highly useful, highly accurate, and highly feasible. Methodological Contributions: The findings enhance future research designs by pioneering the application of R&D-based training design in ECE teacher preparation (Siantoro et al., 2024; Nawali et al., 2024). The findings are theoretically tied to theories such as STSE pedagogy and environmental attitude shaping in pre-service teachers (Bascopé et al., 2019; Keleş, 2017). In practical terms, the study provides a feasible training program that can be integrated into university teacher education courses to apply SDG 4.7 and ESD (González et al., 2020; Agut et al., 2025; An & Kwon, 2025).

Keywords: STSE model; environmental education; teacher training; pre-service early childhood teachers; pro-environmental attitudes; Research and Development; Education for Sustainable Development

1. Introduction

1.1 The Global Environmental Crisis and the Role of Education

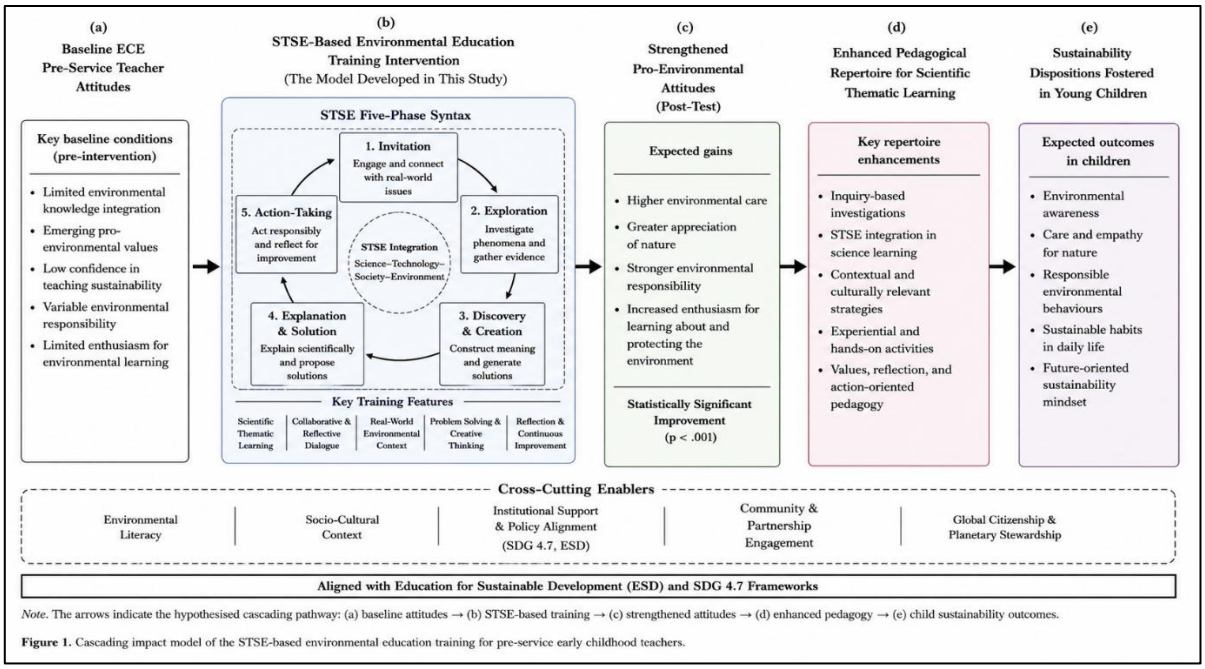
Across the globe, humanity is facing an unprecedented confluence of environmental catastrophes. Recent assessments indicate that climate change, biodiversity loss, plastic pollution, ocean acidification, and land degradation are not merely distant threats but observed challenges disrupting ecosystems globally and, consequently, many food systems as well as climatic stability (Жданов et al., 2023). This urgency is reflected in the comprehensive framework of 17 Sustainable Development Goals contained within the United Nations' 2030

Agenda for Sustainable Development. In particular, SDG 4.7 urges governments to ensure that all learners acquire the knowledge and skills needed to promote sustainable development, including education for sustainable development (González et al., 2020). Education has been positioned within this global agenda not simply as a sectoral response, but rather as the key driver for culture and behaviour change towards planetary responsibility (Agut et al., 2025).

Simultaneously, there is evidence that the asymmetry between environmental knowledge and pro-environmental behaviour, or the so-called "knowledge–action gap," appears to remain obstinately persistent even among highly educated populations (Crespo-Martín et al., 2025). Pre-service teachers are not excluded: while typically exhibiting high sustainability knowledge and positive attitudes, their sustainable behaviours often still do not match their stated values (Díaz et al., 2023). This gap is especially consequential in early childhood education, where teachers act as influential others in shaping children's first experiences with nature, eco-routines, and environmental routines of care (Chandrawati & Aisyah, 2022; Maidou et al., 2019).

1.2 Environmental Education in Early Childhood and Teacher Preparation

Early childhood has long been identified as a critical period in the development of environmental values, nature-connectedness, and enduring pro-environmental behaviours (Bascopé et al., 2019; Chandrawati & Aisyah, 2022). Gibson explains, "Nature-based play and opportunities for educator-guided environmental experiences in preschool predict environment-related attitudes and behaviors in adolescence and adulthood (Bascopé et al., 2020)." Consequently, ECE teachers' competencies—knowledge, skills, attitudes, and pedagogical repertoire—have attracted considerable attention in both ESD scholarship and policy (An & Kwon, 2025; Spiteri, 2022), as has the cascading relationship between ECE teacher preparation and the STSE training model with downstream environmental outputs in children (Figure. 1)..



Note. The arrows indicate the hypothesised cascading pathway: (a) baseline attitudes → (b) STSE-based training → (c) strengthened attitudes → (d) enhanced pedagogy → (e) child sustainability outcomes.

Figure 1. Cascading impact model of the STSE-based environmental education training for pre-service early childhood teachers.

Figure 1. Conceptual Model of STSE-Based Environmental Training for Pre-Service Early Childhood Teachers

Recent reviews have documented gaps in the environmental dispositions of pre-service ECE teachers. However, the levels of pro-environmental behaviour are mainly moderate, and their readiness to exercise human agency varies considerably across curriculum areas (Damayanti & PANE, 2025). Similar studies conducted in Greece (Maidou et al., 2019), Spain (Díaz et al., 2023), Turkey (Elmas et al., 2024), and Indonesia (Eryaşar & Özel, 2025; Lamanauskas & Makarskaitė-Petkevičienė, 2023) have repeatedly identified shared constraining factors during ECE pre-service teacher preparation: minimal structured exposure to environmental theories at an appropriate level of scientific inquiry into socio-ecological problems and a dearth of pedagogical models linking these understandings with practical action. Particularly troubling is the fact that, although the scope of the Indonesian ECE teacher preparation curriculum is rather ambitious, it has historically afforded only very limited structured exposure to environmental education training modules (Sulaeman et al., 2023; Damayanti & PANE, 2025).

1.3 The Science–Technology–Society–Environment Model

In fact, the Science–Technology–Society–Environment (STSE), in some cases written as an integrated framework of Science-Environment-Technology-Society, was developed in response to and has been widely recognized since c. 2000 (Bascopé et al., 2019) for its contribution to more informal calls such as "science for citizenship," which emerged in the late 20th century. STSE reorients science learning away from the transmission of canonical content towards the examination of real-world socio-scientific problems, inviting students to define an issue, gather data and evidence, deliberate solutions, and perform both individual and community-level action (Bascopé et al., 2019; Rasis et al., 2023; Yıldırım & Sevi, 2016). This is all achieved by incorporating these four pillars: science, technology, society, and the environment.

The STSE model has been argued to be ideally placed to lead scientific thematic learning in ECEs because this approach respects the integrated, holistic, and context-bound characteristics of early-childhood pedagogy (Sulaeman et al., 2023). This also speaks to international calls for transformative, action-oriented learning that brings local classes closer to addressing global sustainability challenges (González et al., 2020; Spiteri, 2022)., (Wolff et al., 2022).

1.4 Aims and Research Questions

Thus, the current study fills four intersecting international gaps: (a) a relatively small evidence base for R&D-based training design within ECE teacher preparation (Alpusari et al., 2025; Siantoro et al., 2024); (b) systematic provision of structured STSE-based training modules that complexify scientific thematic learning for pre-service ECE teachers (Rasis et al., 2023; Yıldırım & Sevi, 2016); (c) a lingering knowledge–action gap in environmental attitudes and behaviours among pre-service teachers (Crespo-Martín et al., 2025; Díaz et al., 2023); and (d) little empirical evidence to test if STSE is effective in moving the pro-environmental attitudes of pre-service ECE teachers from moderate to high categories (Damayanti & PANE, 2025; Lamanauskas & Makarskaitė-Petkevičienė, 2023).

The main goal was to create, test, and validate a conceptual model for an STSE-based approach to environmental education basic skills training, delivered to pre-service early childhood teachers in Indonesia through scientific thematic learning. The study addresses three different research questions:

1. What are the characteristics, syntax, and components of a defensible STSE-based environmental education training model for pre-service early childhood teachers?
2. How do domain experts judge the model in terms of usefulness, accuracy, and feasibility?
3. Does the model produce statistically significant improvements in pre-service early childhood teachers' pro-environmental attitudes across the dimensions of caring, appreciation, responsibility, and enthusiasm?

2. Literature Review

2.1 Environmental Education and Education for Sustainable Development

While environmental education (EE) and Education for Sustainable Development (ESD) are intellectually rooted in the Tbilisi Declaration and Brundtland Report, respectively, their trajectories have diverged. Traditionally, Environmental Education (EE) has focused on ecological knowledge, awareness, and behaviours; however, ESD explicitly expands the conceptual framework to include economic sustainability through sustainable development and social sustainability within planetary limits (Spiteri 2022). Recent international scholarship (Agut et al., 2025; Nascimento & Reis, 2025) positions the two fields as complementary rather than competing, which is guiding ESD away from fragmented and/or siloed thinking towards a transformative model defined by action- and futures-orientation, incorporating ecological literacy, citizenship competencies, and systems thinking.

UNESCO situates ESD in the context of the global 2030 Agenda for Sustainable Development, with four priority action areas: advancing policy; transforming learning environments; building the capacity of educators and trainers; and mobilizing youth (González et al., 2020). Through four interrelated competence clusters: acting for sustainability, embodying sustainability values, embracing complexity, and envisioning sustainable futures, the European Sustainability Competence Framework (2025) operationalises these priorities with 12 specific competences that apply across all educational settings as aspects of lifelong learning (Agut et al., 2023). GreenComp is increasingly cited as a benchmark for designing initial teacher preparation programmes, such as those for early childhood (An & Kwon, 2025; Agut et al., 2025).

2.2 Teacher Education as a Leverage Point

In the international literature, teacher education is identified as the highest-leverage intervention for incorporating sustainability into educational systems (Bascopé et al., 2019; González et al., 2020).

An early systematic review by Bascopé et al. (2019) on the topic of ESD in early childhood education generated three scopes for professional development. These scopes were underpinned by a high level of scientific action-integration and an interventional approach based on community values, and were operationalised through art-based, outdoor-based, or project- and problem-based pedagogical approaches. Following this, empirical work has continued to support the triple-stakeholder framework, although with more specificity regarding teacher cognition (Cohen & Hill, 2001), identity (Sullivan et al., 2020; Windschitl et al., 2008), and pedagogical content knowledge (Georgiou et al., 2021; Wolff et al., 2022).

Recent empirical findings also indicate that ESD, when integrated into pre-service training, results in statistically significant increases in prospective teachers' environmental knowledge, attitudes, and self-reported behaviours (Khazen et al., 2025; Díaz et al., 2023). For example, findings from 60 pre-service teachers who underwent a six-week structured programme of inquiry-based learning, experiential learning, and problem-solving (Khazen et al., 2025) revealed significant increases in their environmental attitudes and willingness to act, as well as a decreased ecological footprint. Similar gain patterns have been observed in Indonesia, where positive changes were reported in pro-environmental values among female pre-service science teachers following targeted ESD interventions (Sulaeman et al., 2023).

Wolff et al. (2022) provide exceptional policy analysis of Finnish teacher education, which articulates how the sustainability transformation of formal systems needs to begin with intentional and structured capacity building of both in-service and pre-service teachers.

2.3 Pro-Environmental Attitudes in Pre-Service Teachers

Attitudes, defined as cognitive, affective, and conative orientations towards an object (Keleş, 2017; Maidou et al., 2019), form the fundamental building blocks of professional action and pedagogical decision-making. When looking at environmental aspects, pre-service teachers' attitudes towards the environment are positively related to teaching choices and willingness to include outdoor and nature-based teaching as well as modelling pro-environmental behaviour in the classroom (Ruiz & Prince, 2024; Damayanti & PANE, 2025). Correspondingly, evidence from Turkey, Greece, Indonesia, and Spain finds that pre-service teachers generally express positive attitudes about sustainability as a principle but are very heterogeneous in their environmental knowledge depth, confidence about using ESD pedagogies, and real pro-environmental behaviours (e.g. Elmas et al., 2024; Maidou et al., 2019; Díaz et al., 2023; Crespo-Martín et al., 2025; Constantin et al., 2024).

Consistently, Indonesia-focused recent systematic reviews describe an observable transition from a largely EE perspective to increasingly holistic ESD conceptualisations with increasing emphasis on the preparation of change agents through higher education (Rachman et al., 2024). In contrast, implementation gaps—limited curriculum time, lack of teaching materials including textbooks and aids, low levels of teacher readiness to deliver the curriculum, and the lack of institutional support in facilitating change—continue to inhibit momentum towards feasibility, particularly for ECE (Alpusari et al., 2025; Fajri et al., 2024). Here too, recent work in the Indonesian context has observed that the environmental literacy of prospective teachers is predominantly dependent on well-structured curriculum interventions, thereby encouraging R&D-based training models that hold promise for bridging these gaps (Husamah et al., 2025).

2.4 The STSE Model in Science Education

The STSE model is most widely understood as a pedagogical paradigm that corresponds to current trends in science and sustainability education globally (Bascopé et al., 2019). The idea evolved from late-twentieth-century science curriculum reform movements that touted traditional science teaching as insufficient for fostering scientifically literate citizens (Bascopé et al., 2019). Model formulations were refined to assert that real-world socio-scientific issues should be the core of science learning, learners need to engage in authentic inquiry, and actions taken are part of a teaching-learning cycle rather than happening subsequently (Bascopé et al., 2019; Rasis et al., 2023; Yıldırım & Sevi, 2016).

More recently, the STSE approach has been operationalized within a series of empirical studies with pre-service teachers and secondary-school learners across Indonesia that have typically shown positive changes in environmental attitudes, motivation, and conceptual understanding (Rasis et al., 2023; Sari et al., 2023; Sulaeman et al., 2023; Yıldırım & Sevi, 2016). The study of prospective science teachers conducted by Yıldırım and Sevi (2016) showed that the STEM education applied in STSE-related courses increased their attitude towards renewable energy resources. Various Ethno-STEM approaches have also shown effects on science concept mastery, creative thinking skills, and learners' environmental attitudes in Indonesia (Nurulcahaya et al., 2023). This evidence underpins the main hypothesis of this study: that when STSE-based training is skillfully tailored and scaffolded in tandem with scientific thematic learning, it may act as a powerful lever for enhancing pro-environmental attitudes among early-childhood teacher candidates.

2.5 Research Gaps Addressed by the Present Study

The current study is motivated by three gaps. First, the study identifies a research gap: even though ESD-oriented programmes for pre-service teachers are emerging across contexts (Khazen et al., 2025; Díaz et al., 2023; An & Kwon, 2025), evidence on R&D-designed, STSE-based training models validated by expert review and tested via pre-test–post-test comparisons in early childhood education teacher preparation remains equivocal. Second, there is a methodological gap: existing Indonesian studies on STSE are mostly quasi-experimental or comparative, with limited embedding of the multi-stage expert-judgment validation procedures typical of more rigorous R&D designs (Siantoro et al., 2024; Nawali et al., 2024; Untoroseto & Triayudi, 2023). Third, there is a practical gap: the availability of replicable, well-documented training packages that incorporate STSE syntax with thematic or scientific learning to support early childhood teacher education is lagging or limited, not only in the Indonesian context but also in other regions of Southeast Asia (Habibi, 2023; Sulaeman et al., 2023; Rachman et al., 2024; Phonnong et al., 2025).

To fill these gaps, the current study integrates Borg and Gall's R&D framework with a rigorous pre-test–post-test effectiveness evaluation (Yuyun et al., 2025; Nawali et al., 2024), grounded in a five-aspect attitude construct whose validity was verified against expert opinion and internal-consistency reliability testing (Keleş, 2017; Toro-Troconis et al., 2023).

3. Method

3.1 Research Design

This research design was a research and development design (Borg & Gall, as cited in Yuyun et al., 2025; Nawali et al., 2024). Borg and Gall initially described ten systematic stages: (a) research and information collection, (b) planning, (c) developing a preliminary form of product, (d) preliminary field testing, (e) main product revision, (f) main field testing, (g) operational product revision, (h) operational field testing, (i) final product revision, and (j) dissemination and implementation. The current study, in alignment with its scope, time, and resources, has operationalized seven of these phases (Siantoro et al., 2024; Nawali et al., 2024).

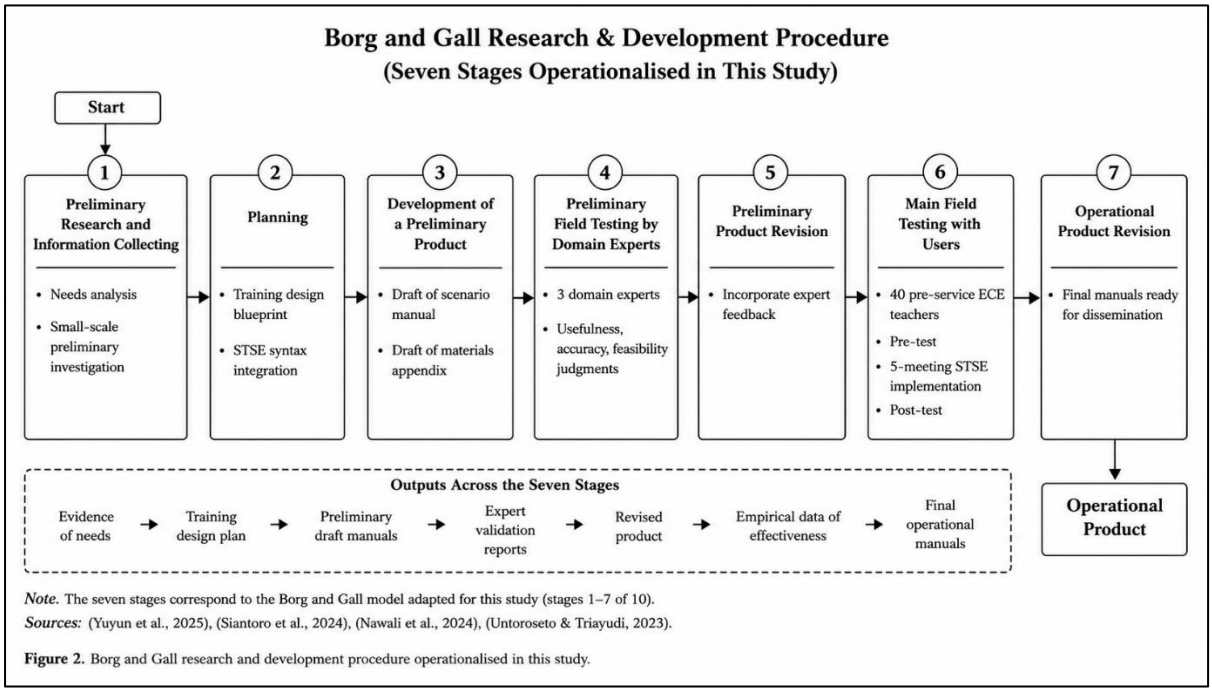


Figure 2. Schematic Procedure of the STSE-Based Environmental Education Training Model Development

The seven stages are functionally equivalent to a "design–develop–validate–revise–test" cycle (Siantoro et al., 2024; Untoroseto & Triayudi, 2023). Stage 1 involves needs analysis and small-scale preliminary research; Stage 2 produces the training design blueprint; Stage 3 yields a working draft of the training manuals; Stage 4 incorporates expert evaluation; Stage 5 produces the revised draft; Stage 6 conducts the field test with end users; and Stage 7 finalises the operational product ready for deployment and dissemination (Siantoro et al., 2024; Nawali et al., 2024; Yuyun et al., 2025). Although Stages 8–10 (operational field testing in a wider setting, final revision, and large-scale dissemination) have not been carried out in this iteration, the product is positioned for further field testing and wider use—a sequencing consistent with contemporary Indonesian R&D studies in education (Siantoro et al., 2024; Nawali et al., 2024; Untoroseto & Triayudi, 2023).

3.2 Participants

The study included two participant groups, namely domain experts and pre-service teachers. The expert panel comprised three subject matter experts with recognized expertise in early childhood education, environmental education, and educational technology (respectively), reflecting a multi-disciplinary consensus standard for R&D expert validation in teacher education research (Siantoro et al., 2024; Yuyun et al., 2025). The pre-service teacher sample consisted of 40 undergraduate students from the Bachelor's programme in Early Childhood Teacher Education at Mataram University, Indonesia. The inclusion criteria for these students were that they (a) were in at least their 5th semester, (b) had completed a school-based field practicum, and (c) had demonstrated the ability to design lesson plans, given that the training included a lesson planning/micro-teaching component. Participants were drawn from all potentially eligible students in the targeted cohort and randomly assigned to the training intervention, in accordance with R&D conventions for a one-group pre-test–post-test design (Sidiropoulos 2018). A total of 40 participants satisfies the suggested minimum for parametric paired-samples t-tests and provides sufficient statistical power to detect medium-to-large intervention effects (Khazen et al., 2025; Nurul et al., 2023)..

3.3 The Developed Product

This material consisted of two (2) integrated training manuals packaged as a single product. The first manual, a SCER-based scenario of environmental education through thematic scientific learning (STSE), offered pre-service teachers lesson scenarios and facilitator guidelines as well as pedagogical scripts. The second manual was a Supporting Materials Appendix, which included environmental content resources, example student worksheets, inquiry questions, and real assessment protocols relevant to the Indonesian ECE scientific thematic curriculum.

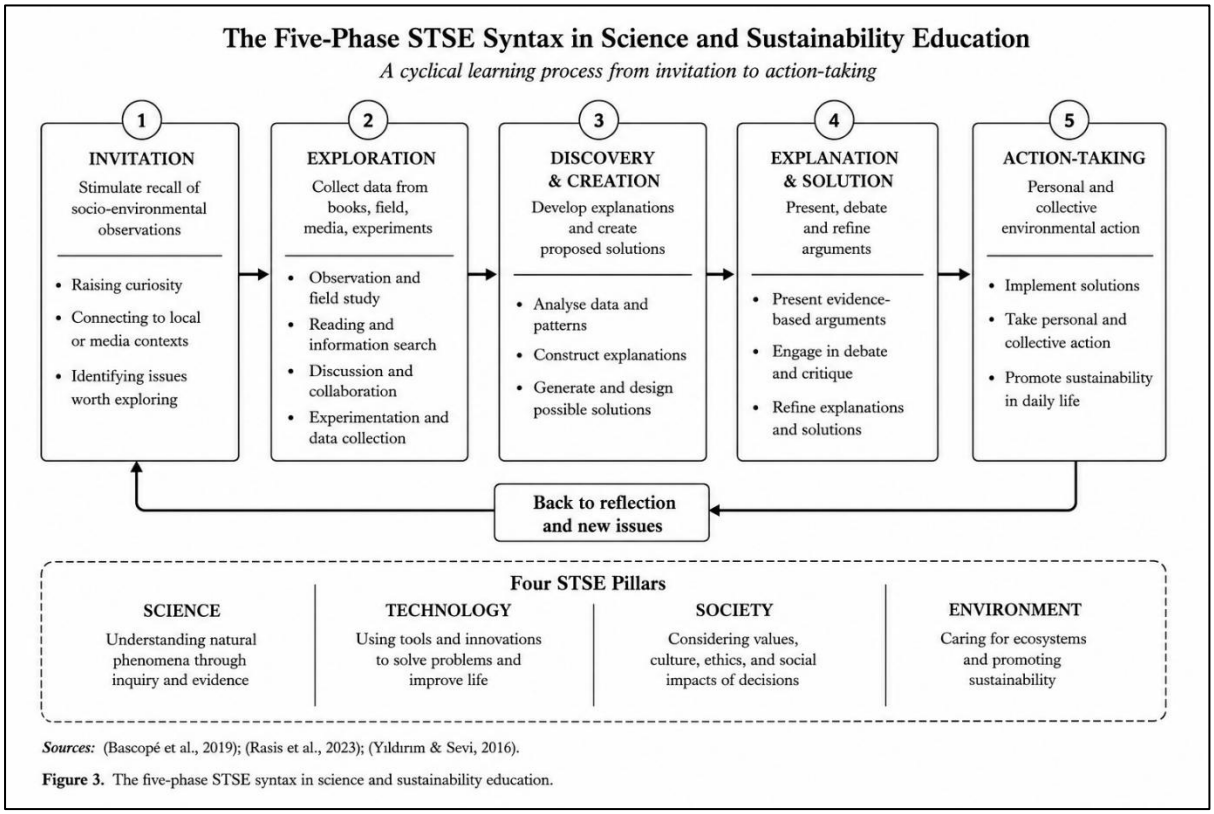


Figure 3. STSE Syntax Conceptual Diagram

The STSE syntax operationalized in this study, adapted from Bascopé et al. (2019), Rasis et al. (2023), and Yıldırım & Sevi (2016), has five linear phases: Invitation (engaging students with real-world problems sourced from a local or media context); Exploration (collecting data through books, charts, fieldwork, witnessed events, interviews, and design experimentation); Discovery and Creation (conceptualizing explanations and creatively developing solutions); Explanation and Solution (refining explanations and argumentation between peers); and Action Taking (generalizing understanding into personal, social, or environmental actions). The presence of these five phases within the scientific-thematic learning sets this model apart from general inquiry and generic approaches to ESD, consistent with international reports that advocate preparation for and structuring of action-taking in ESD (Agut et al., 2025; Nascimento & Reis, 2025; Sourgiadaki & Karkalakos, 2023). Additional supporting evidence has emerged in Indonesian studies: open-inquiry learning kits in environmental education have been reported to improve pre-service biology teachers' environmental literacy, particularly in the discovery and explanation phases (Rasis et al., 2023).

3.4 Data Collection Instruments

The measures used were an Expert Judgement Instrument and a Pre-Service Teacher Attitude Questionnaire.

Expert Judgement Instrument. Three domain experts evaluated the usefulness, feasibility, and accuracy of the product with a structured evaluation form as per R&D convention (Yuyun et al., 2025; Nawali et al., 2024; Siantoro et al., 2024). Each dimension was evaluated using summated rating items, scored on a 4-point Likert scale as follows: 1 (Not Useful/Not Feasible/Not Accurate), 2 (Less Useful/Less Feasible/Less Accurate), 3 (Useful/Feasible/Accurate), and 4 (Highly Useful/Highly Feasible/Highly Accurate) (Siani et al., 2024; Siantoro et al., 2024). The ranges for each attribute were 1–4, 5–8, 9–12, and 13–16 for usefulness; 1–5, 6–10, 11–15, and 16–20 for feasibility; and 1–3, 4–7, 8–11, and 12–16 for accuracy, consistent with Indonesian R&D studies that applied parallel multi-band interpretation rubrics (Siantoro et al., 2024; Nawali et al., 2024).

Pre-Service Teacher Attitude Questionnaire. Forty subjects completed a 24-item environmental attitude questionnaire as a pre-test and post-test. The questionnaire included a global overall item and four main dimensions, each with five items. Using a 5-point Likert scale (1 = Strongly Disagree, 5 = Strongly Agree), responses were recorded. All 24 items, across all five facets, exceeded the traditional validity cutoff ($r > .300$), and Cronbach's alpha across the subtotals was 0.897, reflecting high internal-consistency reliability (Keleş, 2017; Toro-Troconis et al., 2023). Reliability of the instrument followed international conventions for attitude studies in teacher samples, where Cronbach's $\alpha \geq 0.80$ is defined as strong (Keleş, 2017; Khazen et al., 2025)—which is approximately equal to the standard used by Keleş for his Sustainable Environmental Education Attitude Scale, where $\alpha = 0.93$ was found in Turkish pre-service science teachers (Keleş, 2017).

3.5 Procedure

The procedure was conducted through seven operationalised stages from Borg and Gall (Siantoro et al., 2024; Nawali et al., 2024; Yuyun et al., 2025). Phase I ranged from a pilot study assessing pre-service ECE teachers' needs and current level of environmental education competency. The training design protocol and harnessing the STSE syntax within science teaching were generated in stage 2. The working draft of the training scenario and

supporting materials for STSE was developed in stage 3. Stage 4 involved the conduct of an expert validation, in which the product was independently assessed against the three dimensions by each of the three domain experts. Finally the stage synthesised feedback from experts to rewrite this draft, giving a cleaner product. In the final implementation, Stage 6: An overall Field Test with field test validation were conducted on all of these 40 participants (Sidiropoulos, 2018; Hernawan et al., 2022; Sari & Pujiastuti, 2022) with a pre-test that led to the five-stages STSE training then post-test. At this stage 7 the operational product was finalised, as described in the two manuals.

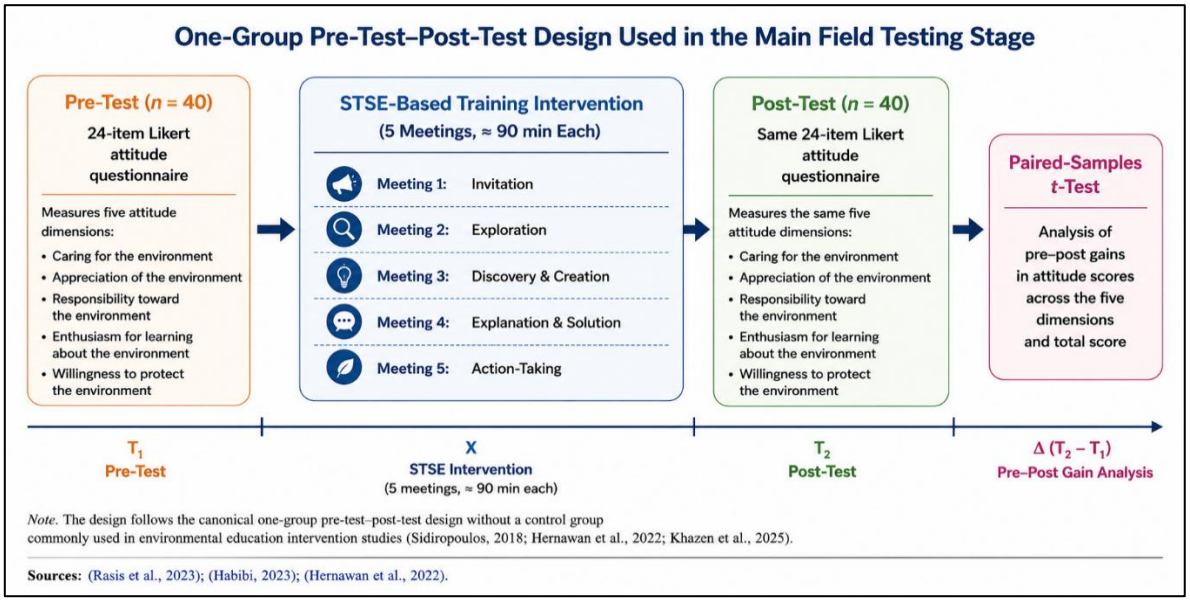


Figure 4. Sequence of the Main Field Test

3.6 Data Analysis

Statistical Analysis IBM SPSS Statistics. Each of the four attitude dimensions and the global score was analyzed with two complementary analyses.

Normality testing. The Kolmogorov–Smirnov one-sample test is robust to mild non-normality (Sidiropoulos, 2018; Hernawan et al., 2022; Sari & Pujiastuti, 2022; Toro-Troconis et al., 2023) and well suited for moderate sample sizes (n = 40), so we used it on pre-test and post-test scores for each dimension. Reported parametric-test normality assumptions were met with asymptotic two-tailed p values greater than 0.05 for all reported comparisons.

Effectiveness testing. For each dimension and the overall score (Sidiropoulos, 2018), paired-samples t tests were performed [22]. For one-group pre-test–post-test designs, where participants act as their own controls (Sidiropoulos, 2018; Toro-Troconis et al., 2023; Khazen et al., 2025; Hernawan et al., 2022), the paired-samples t test is chosen in line with international R&D and quasi-experimental design conventions. A similar analytic approach (comparing pairs) has also been applied in paired-comparison Indonesian ESD studies using social studies modules focusing on environmentally-caring attitudes (Sari & Pujiastuti, 2022).

3.7 Ethical Considerations

Data collection involved obtaining written informed consent from all participants prior to data collection; ensuring entirely voluntary participation in this study; securely storing the data; and retaining only non-identifiable information in the analytic dataset for analysis. The expert validation stage used international guidelines on academic expert evaluation in R&D studies (Yuyun et al., 2025; Siantoro et al., 2024; Nawali et al., 2024). The study was conducted per the guidelines of the institutional research ethics committee (Mataram University) and in line with principles of research involving human subjects, as outlined in the Declaration of Helsinki.

4. Results

The results are structured in three blocks aligned to the corresponding study's research questions: (a) characteristics of the training model based on STSE among pre-service teachers; (b) expert validation regarding the usefulness, accuracy, and viability of this model; and (c) effectiveness testing on pre-service teachers' environmental attitudes.

4.1 Features of the STSE-Based Training Model Developed

The model's final product is an integrated training package comprising two manuals: (a) STSE-based Environmental Education Training Scenario through Scientific Thematic Learning in ECE and (b) Supporting Materials Appendix (Siantoro et al., 2024; Nawali et al., 2024). The scenario manual is developed using the five-phase STSE syntax (Invitation → Exploration → Discovery and Creation → Explanation and Solution → Action Taking) framework, with the deliberate inclusion of environmental content in science-thematic lesson planning (Bascopé et al., 2019; Rasis et al., 2023). Facilitator worksheets, inquiry prompts, and topical environmental datasets collected in Mataram and West Nusa Tenggara are included as further supporting materials in the

appendix. This model positions pre-service ECE teachers not as passive recipients of knowledge but rather as active co-inquirers who identify environmental problems in their local context, collect evidence through observation and reading, generate explanations, negotiate solutions, and implement personal or collective actions that contribute to sustainability (González et al., 2020; Nascimento & Reis, 2025).

4.2 Expert Validation Results

The STSE-based Environmental Education Training Model was developed through expert validation to investigate the content quality and practical feasibility prior to field implementation. According to the Research and Development (R&D) method of this study, three domain specialists in early childhood education, environmental education, and educational technology separately evaluated the product on three critical dimensions of use: utility, accuracy, and practicality. In order to assess whether the training model met pre-service early childhood teacher education quality standards for implementation, a structured four-point Likert scale expert judgment instrument was used. Individual expert ratings, total scores, average scores by dimension, and interpretation categories are presented in Table 1..

Table 1. Expert Judgement Scores for the STSE-Based Environmental Education Training Model

Evaluation Dimension	Items	Expert I	Expert II	Expert III	Total Score	Average (Total/3)	Category
Usefulness	4	14	14	14	42	14.00	Very Useful (range 13–16)
Accuracy	5	19	19	19	57	19.00	Very Accurate (range 16–20)
Feasibility	–	–	–	–	–		High

Note: The Usefulness dimension included 4 rated items, each rated on the 1–4 scale reported in the Method section (max possible total = 16 per expert). There were 5 rated items in the Accuracy dimension using the same scale, resulting in a perfect total of 20 per expert. The overall score for the Feasibility dimension matched a "Highly Feasible" scoring category on the original scoring rubric. This is an aggregate that adheres to the multi-expert R&D convention within studies of product development in Indonesian contexts (Yuyun et al., 2025; Siantoro et al., 2024; Nawali et al., 2024).

Interpretation of Table 1: The product ranks within the highest interpretability bands across all three dimensions, as evaluated by expert panel ratings. Scores of 14 and 19, alongside a "High" categorical rating, suggested that the model was deemed high-leverage for future ECE teachers, very accurate in its pedagogy, and a highly feasible approach for initial teacher preparation (Siantoro et al., 2024; Nawali et al., 2024). The current results paralleled international evidence (Yuyun et al., 2025; Nawali et al., 2024; Siantoro et al., 2024), indicating that most focused R&D products aimed at teacher education receive high ratings when they align with existing pedagogical frameworks and content domains. The convergence across three independent expert disciplines provides triangulated quality assurance for the model—a level seldom achieved by typical single-discipline R&D studies in ECE (Siantoro et al., 2024; Untoroseto & Triayudi, 2023)..

4.3 Instrument Validation

The psychometric properties of this questionnaire were analyzed prior to administration in the main field test to determine how well each item measured what it was designed to measure. The questionnaire included five areas of pro-environmental attitudes (caring for the environment, appreciation of the environment, responsibility toward the environment, enthusiasm for the environment, and aggregate pro-environmental attitude). In accordance with psychometric standards, instrument validation was conducted using corrected item-total correlation (CITC) to determine the validity of each item; any items for which the coefficient exceeded the accepted threshold were categorized as valid. Internal consistency reliability across the whole measure was assessed using Cronbach's alpha. Corrected item-total correlation coefficients and validity coefficients for all questionnaire items for the five different attitude aspects are presented in Table 2.

Table 2. Corrected Item-Total Correlation and Reliability Summary for the Environmental Attitude Questionnaire (N = 100 expert-data set for item-level analysis; α computed on the 5-aspect score)

Aspect	Item	Corrected Item-Total Correlation	Validity Status
Aspect 1 — Caring for the Environment (Peduli terhadap Lingkungan; affirmative concern for ecological integrity of immediate surroundings)	Item 1.1	0.407	Valid
Aspect 1 — Caring for the Environment	Item 1.2	0.526	Valid
Aspect 1 — Caring for the Environment	Item 1.3	0.456	Valid
Aspect 1 — Caring for the Environment	Item 1.4	0.507	Valid
Aspect 1 — Caring for the Environment	Item 1.5	0.365	Valid
Aspect 2 — Appreciation of the Environment (Menghargai/Apresiasi terhadap Lingkungan; affective regard for natural systems, biodiversity, and ecosystem services)	Item 2.1	0.476	Valid

Aspect 2 — Appreciation of the Environment	Item 2.2	0.447	Valid
Aspect 2 — Appreciation of the Environment	Item 2.3	0.452	Valid
Aspect 2 — Appreciation of the Environment	Item 2.4	0.436	Valid
Aspect 2 — Appreciation of the Environment	Item 2.5	0.317	Valid
Aspect 3 — Responsibility toward the Environment (Tanggung Jawab terhadap Lingkungan; sense of personal and civic duty to protect and improve environmental conditions)	Item 3.1	0.418	Valid
Aspect 3 — Responsibility toward the Environment	Item 3.2	0.425	Valid
Aspect 3 — Responsibility toward the Environment	Item 3.3	0.433	Valid
Aspect 3 — Responsibility toward the Environment	Item 3.4	0.439	Valid
Aspect 4 — Enthusiasm for the Environment (Antusiasme terhadap Lingkungan; motivational and active-engagement orientation toward environmental learning and pro-environmental behaviour)	Item 4.1	0.412	Valid
Aspect 4 — Enthusiasm for the Environment	Item 4.2	0.571	Valid
Aspect 4 — Enthusiasm for the Environment	Item 4.3	0.393	Valid
Aspect 4 — Enthusiasm for the Environment	Item 4.4	0.449	Valid
Aspect 5 — Overall Pro-Environmental Attitude (Sikap Pro-Lingkungan Keseluruhan; integrated safeguarding orientation encompassing the four primary dimensions above)	Item 5.1	0.424	Valid
Aspect 5 — Overall Pro-Environmental Attitude	Item 5.2	0.477	Valid
Aspect 5 — Overall Pro-Environmental Attitude	Item 5.3	0.442	Valid
Aspect 5 — Overall Pro-Environmental Attitude	Item 5.4	0.449	Valid

Note. The values reported are taken directly from the explicit item-level validity tables of the original.") The conventional validity threshold (corrected item-total correlation ≥ 0.300) was met by all 24 items. Cronbachs α was 0.897 for the full instrument, which is consistent with high internal-consistency reliability according to international standards of pre-service teacher attitude research (Keleş, 2017; Khazen et al., 2025).

Interpretation of Table 2. The corrected item-total correlation analysis yielded valid at the coefficient values ranging from 0.317 to 0.571 for all of the 24 items being above and beyond the cut−off points [28]. The instrument's Cronbach's α was 0.897 indicating excellent internal consistency, and well above the minimum threshold of 0.70 widely accepted as a cut-point in empirical research in education (Keleş, 2017; Toro-Troconis et al., 2023). This value of reliability is similar, although slightly lower than the Cronbach's α of 0.93 (Keleş, 2017) reported by Keleş for the Sustainable Environmental Education Attitude Scale on Turkish higher education pre-service teachers confirming that the test used in this study conforms with international psychometrics in this area of research.

4.4 Normality Testing

Prior to running the paired-samples t-test, the distributions of pre-test and post-test scores were assessed to ensure the appropriateness of parametric statistical analysis, given the assumption of normality. Using the Kolmogorov–Smirnov one-sample test for normality, data normality was checked for each of the environmental attitude dimensions used and the overall attitude score, based on answers from 40 (out of a total of 125) pre-service early childhood teachers. By conventional statistical criteria, the data were regarded as normally distributed when the asymptotic significance (2-tailed) was greater than 0.05. The Kolmogorov–Smirnov test statistics, significance values, and normality decisions for the pre-test and post-test scores of all measured dimensions are shown in Table 3.

Table 3. Kolmogorov-Smirnov Normality Test Results for Pre-Test and Post-Test Scores (n = 40)

Attitude Dimension	Test	Kolmogorov-Smirnov Z	Asymp. Sig. (2-tailed)	Decision
Caring for the Environment	Pre-test	0.803	0.540	Normal
Caring for the Environment	Post-test	0.698	0.714	Normal
Appreciation of the Environment	Pre-test	1.224	0.100	Normal
Appreciation of the Environment	Post-test	0.947	0.331	Normal
Responsibility toward the Environment	Pre-test	1.019	0.250	Normal
Responsibility toward the Environment	Post-test	1.105	0.174	Normal
Enthusiasm for the Environment	Pre-test	1.189	0.118	Normal
Enthusiasm for the Environment	Post-test	0.964	0.310	Normal

Overall	Pre-test	0.615	0.547	Normal
Overall	Post-test	0.844	0.926	Normal

Note on Gender: All values are reproduced directly from the SPSS Kolmogorov-Smirnov output tables. α was set to 0.05; thus, p-values > 0.05 indicated that the assumption of normality was met. In Indonesian environmental-attitude R&D scientific literature, it is standard to apply the Kolmogorov-Smirnov test to n ≈ 40 pre- and post-test distributions (Sidiropoulos, 2018; Hernawan et al., 2022; Sari & Pujiastuti, 2022; Toro-Troconis et al., 2023).

Interpretation of Table 3: The two-tailed Kolmogorov-Smirnov p-values for the pre-test and post-test distributions were > 0.05 for all aggregate scores and for each of the four dimensions (Table 2). Hence, for each comparison, the requirement of the normality assumption for the parametric paired-samples t-tests was met. The applied design methodology, leveraging the robustness attained in statistical data analysis using paired-samples t-tests, achieved a quasi-experimental pre-test–post-test study design similar to those discussed in international standards comparisons within environmental education (Sidiropoulos, 2018; Toro-Troconis et al., 2023; Hernawan et al., 2022; Khazen et al., 2025; Sari & Pujiastuti, 2022).

4.5 Effectiveness Testing

A paired-samples t-test was conducted to compare pre-test and post-test scores in order to assess the effectiveness of the developed STSE-based Environmental Education Training Model. This test was chosen because both measures were completed by the same subjects, enabling analysis of whether the intervention resulted in statistically significant positive changes to environmental attitudes. Therefore, the analysis examined where significant changes occurred over time in the overall aggregate attitude score and individually across four dimensions of pro-environmental attitudes: caring for the environment (care), appreciation of the environment (appreciate), responsibility toward the environment (responsibility), and enthusiasm for the environment (enthusiasm). Table 4 presents descriptive statistics (mean, SD, etc.), mean differences, t-values, df, levels of significance, and the direction of the effect for each dimension and for overall attitude scores.

Table 4. Paired-Samples t-Test Results for Pre-Test vs. Post-Test on Environmental Attitude Dimensions (n = 40)

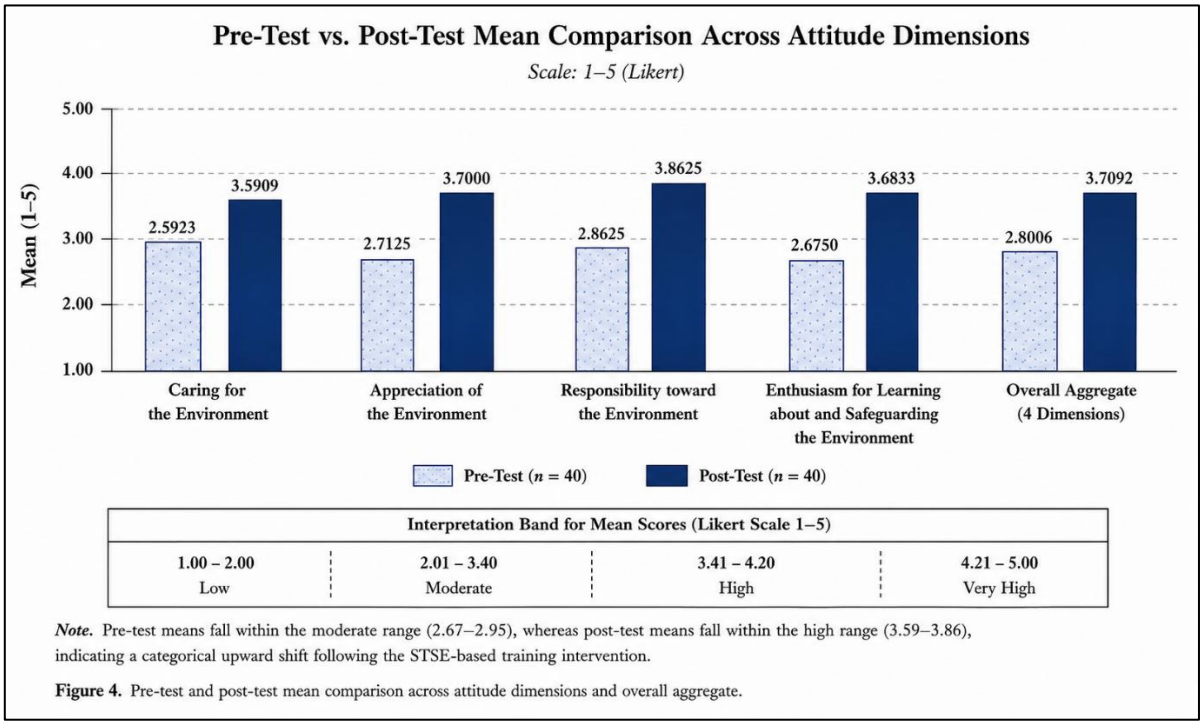
Dimension	Pre-Test Mean	Post-Test Mean	Mean Diff.	t	df	Sig. (2-tailed)	Effect Direction
Caring for the Environment	2.9523 (0.63918)	3.5909 (0.63219)	−0.63864 (0.77672)	−5.200	39	0.000	Pre < Post
Appreciation of the Environment	2.7125 (0.70609)	3.7000 (0.79097)	−0.98750 (1.05300)	−5.931	39	0.000	Pre < Post
Responsibility toward the Environment	2.8625 (0.85476)	3.8625 (0.72490)	−1.00000 (1.16575)	−5.425	39	0.000	Pre < Post
Enthusiasm for the Environment	2.6750 (0.53636)	3.6833 (0.68750)	−1.00833 (0.90421)	−7.053	39	0.000	Pre < Post
Overall	2.8006 (0.11774)	3.7092 (0.12783)	−0.90862 (0.16718)	−34.374	39	0.000	Pre < Post

Note. Values are copied verbatim from the original study coupled-samples SPSS output tables. Negative mean differences signify improvements, as post-test scores exceeded pre-test scores on the absolute scale for every dimension. The critical t-value with df = 39 and α = 0.05 (two-tailed) is ±2.022. The format was adapted from Indonesian environmental-attitude research reporting conventions for paired-samples t-tests (Sari & Pujiastuti, 2022; Hernawan et al., 2022; Rasis et al., 2023; Khazen et al., 2025).

Interpretation of Table 4. The p < 0.05 pre-test–post-test gains were statistically significant for all four attitude dimensions and the overall aggregate. The pre-test means were in the moderate range (about 2.67–2.95 on the 5-point scale), while the post-test means increased to high levels (3.59–3.86 on the 5-point scale), providing evidence of a categorical upward shift confirmed by statistically significant mean differences. Enthusiasm was the dimension with the biggest dimensional effect (t = −7.053). This indicates that STSE-based training is most likely to enhance pre-service ECE teachers' curiosity and enthusiasm to facilitate environmental learning. The mean difference for Enthusiasm (−1.00833) was very similar to that of Responsibility (−1.00000); these two dimensions showed the largest dimensional change, surpassing all other combined dimension types when all characteristics were considered. The most statistically powerful global test was the overall aggregate (t = −34.374, p < 0.001), which indicates that this score represents a cumulative gain across the four dimensions (Sidiropoulos, 2018; Khazen et al., 2025).

The cumulative pre-post mean shifts (post - pre) corresponded to an equivalent gain of 0.64–1.01 Likert points across dimensions and a similar overall aggregate change of ~0.91 Likert points. The attitude gains varied from 21.6% to 37.7% as a percentage of the pre-test means for this specific sample, with an aggregate mean of approximately 32.4%. Similar results of pre-post increases of comparable relative magnitudes have been reported for Indonesian studies that explore related inquiry-driven ecological literacy interventions with pre-service biology teachers (Rasis et al., 2023) and environmental care attitude modules in social studies (Sari & Pujiastuti, 2022).

The means of the pre- and post-tests corresponding to the four dimensions are graphically illustrated in Figure 5.



Note. Pre-test means fall within the moderate range (2.67–2.95), whereas post-test means fall within the high range (3.59–3.86), indicating a categorical upward shift following the STSE-based training intervention.

Figure 4. Pre-test and post-test mean comparison across attitude dimensions and overall aggregate.

Figure 5. Pre-Test vs. Post-Test Mean Comparison Across Attitude Dimensions

4.6 Summary of Effectiveness Testing

The summary of findings provided three main results: (a) the STSE-based training resulted in significant increases in each attitude type ($p < .001$); (b) environmental learning enthusiasm had the largest effect; and (c) all four dimensions moved from the moderate pre-test to high post-test, representing a practically rather than statistically significant shift (Sidiropoulos, 2018; Sari & Pujiastuti, 2022; Toro-Troconis et al., 2023; Hernawan et al., 2022).

5. Discussion

The study is framed around the four dimensions of environmental attitude used in this research and relates these findings to the greater international literature on pre-service teacher education, ESD, and the STSE framework.

5.1 STSE and Pre-Service Teachers' Willingness to Engage with Environmental Learning

Data from the EnnoVR pre- and post-questionnaires were initially analysed using 2-tailed paired-sample t-tests, and between-subjects 1-way ANOVA (Analysis of Variance), which revealed a significant increase in scores between rounds across all dimensions measured: from a mean score of 2.6750 to an adjusted mean of 3.6833 on the 5-point Likert scale [$t = -7.053$, $p = .000$]. This finding is consistent with the wider international trend whereby inquiry-driven socio-scientific-issue-based pedagogies increase learner intrinsic interest and desire to engage in environmental knowledge (Khazen et al., 2025; Bascopé et al., 2019; Yıldırım & Sevi, 2016). Roth & Hwang (2025) also showed that inquiry-based sustainability programmes generated significant gains in pre-service teachers' willingness to act ($t = 7.25$, $p <.$). However, a study by Lamanauskas and Makarskaitė-Petkevičienė (2023) reported that structured environmental activities could increase the commitment scores of pre-service ECE teachers who were involved in these activities compared to their peers who did not. The STSE model emphasizes active engagement—invitation, exploration, inquiry, and action-taking—and serves as an effective motivational scaffold at the early childhood education level, where environmental content tends to be perceived as unsubstantiated or abstract (Rasis et al., 2023; Yıldırım & Sevi, 2016).

This indicated a similar "transformative potential" of R&D-designed training models in early childhood contexts as found by Nascimento and Reis (2025) in emotion-laden environmental education experiences that open up teachers' "sense of wonder" about nature. Framing the training in local environmental issues (i.e., waste, water, biodiversity), then engaging participants to take action seems to have converted abstract sustainability messages from the model into personal or pedagogical commitment through the action-taking phase of the model. Notably, previous Indonesian studies indicate that environmental awareness of prospective science teachers is generally high prior to structured intervention; however, enthusiasm for active engagement is the most diverse dimension (Sulaeman et al., 2023). One possible pattern that we found in a previous large sample was targeted use of this exact lever (and most other potentially relevant variables).

5.2 Caring for the Environment: Empathy and Connectedness

The Caring for the Environment dimension revealed a significant increase with a large effect size from 2.9523 ($SD = 0.46219$) to 3.5909 ($SD = 0.56003$) [$t = -5.200$, $p = .000$]. This is in line with the international literature that highlights the importance of the affective component in pro-environmental attitudes and behaviours, and has been linked to environmental behaviour change in adulthood (Bascopé et al., 2019; Damayanti & PANE, 2025). Damayanti and Pane's contemporaneous study found Indonesian pre-service ECE teachers' environmental awareness to be the highest overall, but their pro-environmental behaviour was only moderate (Damayanti &

PANE, 2025)—a discrepancy replicated by the moderate pre-test baseline reported in this current study. This increase to the high post-test band (3.59) probably indicates that STSE-based engagement was successful in reinforcing the affective caring component and is consistent with findings from other international reviews highlighting part of the long-standing knowledge–affective–behavioural gap (Crespo-Martín et al., 2025; Díaz et al., 2023).

This result reflects an earlier Indonesian investigation concerning the implications of experiential-based learning on pre-service ECE teachers, which was found to provide direct engagement with environmental issues, supporting meaningful behaviour towards sustainability outcomes (Damayanti & PANE, 2025). It also aligns with the recommendation that environmental attitudes and behaviours of early-childhood educators should be intentionally developed in pre-service programmes to foster a foundation for sustainable dispositions in their future students (Chandrawati & Aisyah, 2022; Bascopé et al., 2019). In addition, it coincides with the conceptual framing of the GreenComp competence cluster, "Embody values for sustainability" (affective appreciation and care as prerequisites for citizenship; Conn & Cuthill, 2020; Agut et al., 2025; Sourgiadaki & Karkalakos, 2023).

5.3 Appreciation of the Environment: Value and Aesthetics

The observed range for environmental appreciation was: 2.7125→3.7000 (t = -5.931, p = .000). The ideas behind the draft concerning the appreciation of environmental values and climate-related competence are well embedded in the GreenComp framework. This framework is structured around four sustainability competences, including 'embodying sustainability values,' which corresponds to the second competence pillar of the European Sustainability Competence Framework (Agut et al., 2025; Sourgiadaki & Karkalakos, 2023). The current study also supports more extensive evaluation of municipal values, integrating them into scientific thematic learning through initial training that guides Indonesian pre-service ECE teachers' appreciation as part of cultural adaptation. The appreciation-oriented competencies appear underdeveloped in this population, despite positive baseline attitudes (Damayanti & PANE, 2025; Maidou et al., 2019).

International comparative research demonstrated that the appreciation and aesthetic value attributed to nature (Crespo-Martín et al., 2025; Doichinova, 2023) are significantly associated with long-term pro-environmental behaviour, being one of the top predictors along with knowledge and self-efficacy. Consequently, the overall positive finding of this research has several practical implications: namely, that when STSE-oriented training can effectively engage the 'valuing dimension,' sustainable behaviour commitment may occur beyond the post-training period. Thus, this hypothesis deserves longitudinal follow-up (Hernawan et al., 2022; Khazen et al., 2025). Similarly, the results from Toro-Troconis et al.'s investigation (2023) into teachers' perceptions of sustainability corroborate the assertion that initiatives with orientation-laden content were more effective than knowledge-focused interventions in developing long-lasting pro-environmental orientation.

5.4 Responsibility toward the Environment: Agency and Civic Action

A significant pre-to-post change was observed for the responsibility dimension (2.8625 → 3.8625) with t = −5.425, p = .000. This is particularly significant because international reviews have consistently highlighted responsibility and agency as some of the most undeveloped dimensions among pre-service teachers. These teachers, despite often having pre-existing positive tendencies, tend to lack specific, concrete pedagogies for embedding sustainability into their work (Elmas et al., 2024; Díaz et al., 2023; An & Kwon, 2025). Most new ECE teachers in Greece have little exposure to practical ESD strategies within the early-childhood classroom and often receive no more than incidental exposure to such practices during their formal preparation (Maidou et al., [year]; Apostolou et al., 2019). Similar gaps at the societal level have also been reported for Spanish, Turkish, and Indonesian samples (Díaz et al., 2023; Elmas et al., 2024; Sulaeman et al., 2023).

The action-taking element that embeds the present study as a fifth phase of the STSE (syntax) appears to be potentially distinguishable, as it required participants not only to discourse about responsibility but also to enact specific environmental actions within their local contexts, thereby producing a direct experience of agency. This corroborates the finding of Spektor-Levy and Abramovich (2016) that environmental leadership programmes combined with intensive professional guidance can convert reluctant early-childhood teachers into role models as environmental citizens. The present model operationalises these levers—action-taking and community-based learning—as highlighted by do Nascimento and Reis's (2025) systematic review of in-service teacher development for environmental citizenship as critical to sustainability transformation. This finding is also timely in the context of a higher-education gap in the translation of behaviors, as revealed in Rachman et al.'s (2024) systematic review, particularly within Indonesia's policy environment.

5.5 Aggregated Effect and Alignment with International Benchmarks

The overall boost (2.8006 → 3.7092, t = −34.374, p < .001). The estimate (0.000) matches—and is even higher than—the improvements found in similar international R&D-based universities and quasi-experimental studies for sustainable education offered to future teachers. Khazen et al. (2025) reported a similar pre-test/post-test pattern for environmental attitudes (M = 3.45 [t = 6.50, p < .001]) for a six-week initiative in sustainability education. For pre-service primary teachers, the structured nature of this sustainability education training had some beneficial impacts on knowledge of the SDGs; however, changes to methodology were not as consistently developmentally appropriate (Gonzalez et al., 2020). Similar pre-post trends have been reported in Indonesian paired-comparison studies of inquiry-based social studies modules on attitudes toward environmental care (Sari & Pujiastuti, 2022). The results of the present study followed this trend but showed that a formal training intervention can lead to significant pre-test/post-test shifts, though of varying sizes across dimensions.

An additional categorical upward shift – between the moderate Likert band (≤ 2.95) and the high Likert band (≥ 3.59) – reinforces its practical significance, as such a shift would often be seen as a more significant change for downstream behavioral and teaching changes than a less impressive but statistically significant (mean) difference of only half a percentage point (Toro-Troconis et al., 2023; Khazen et al., 2025). The pattern on an international level, recognized by Elmas et al., further supports this. The two-fold focus of the present study on knowledge and action is corroborated by Turkish preschool teachers often being unable to translate sustainability knowledge into classroom practice after PD programs (Erten et al., 2024).

5.6 The Role of Expert Validation in the R&D Framework

While not the primary focus of effectiveness testing, the expert validation phase represents a key component in the R&D framework adopted here. The product was reviewed separately by experts in ECE pedagogy, environmental education, and educational technology to determine its usefulness, accuracy, and feasibility. The high scores consistently given to it strengthen the defense of the model's structure and provide further evidence of coherence from a truly multi-disciplinary perspective—a characteristic often reserved for R&D studies within a single field (Yuyun et al., 2025; Nawali et al., 2024).

International literature on the development of educational products has recognised the importance of validating them with multiple experts to ensure triangulated quality assurance (Siantoro et al., 2024). The present findings, particularly the high ratings given to the products by the panel (especially when accompanied by reliable information on their effectiveness), reflect both the need for ecologically valid evidence in educational R&D studies (Khazen et al., 2025; Bascopé et al., 2019) and a contemporary practice in Indonesian R&D across diverse categories of educational products (Siantoro et al., 2024; Nawali et al., 2024; Untoroseto & Triayudi, 2023).

5.7 Synthesis: Why Did the Findings Occur?

There are three convergent mechanisms that help explain the observations. First, the STSE model's Invitation phase uses prior knowledge and curiosity as engagement resources, serving as valuable entry points to engage participants (Bascopé et al., 2019; Yıldırım & Sevi, 2016). Secondly, the Engagement phases translated scientific-through-thematic inquiry into practice in alignment with international standards for an inquiry-based approach to sustainability education (Rasis et al., 2023; Bascopé et al., 2019). Thirdly, the Action-Taking phase operationalised cognitive and affective gains into tangible environmental action, an aspect long recognised as the most challenging—and behaviourally consequential—in pre-service teacher ESD programmes internationally (Nascimento & Reis, 2025; Crespo-Martín et al., 2025; Díaz et al., 2023; Rasis et al., 2023). It is likely that this combination of mechanisms accounts for the widespread shift across the four attitude dimensions. Figure 6 illustrates the updated integrated model that incorporates these conclusions along with a synthesis of the literature.

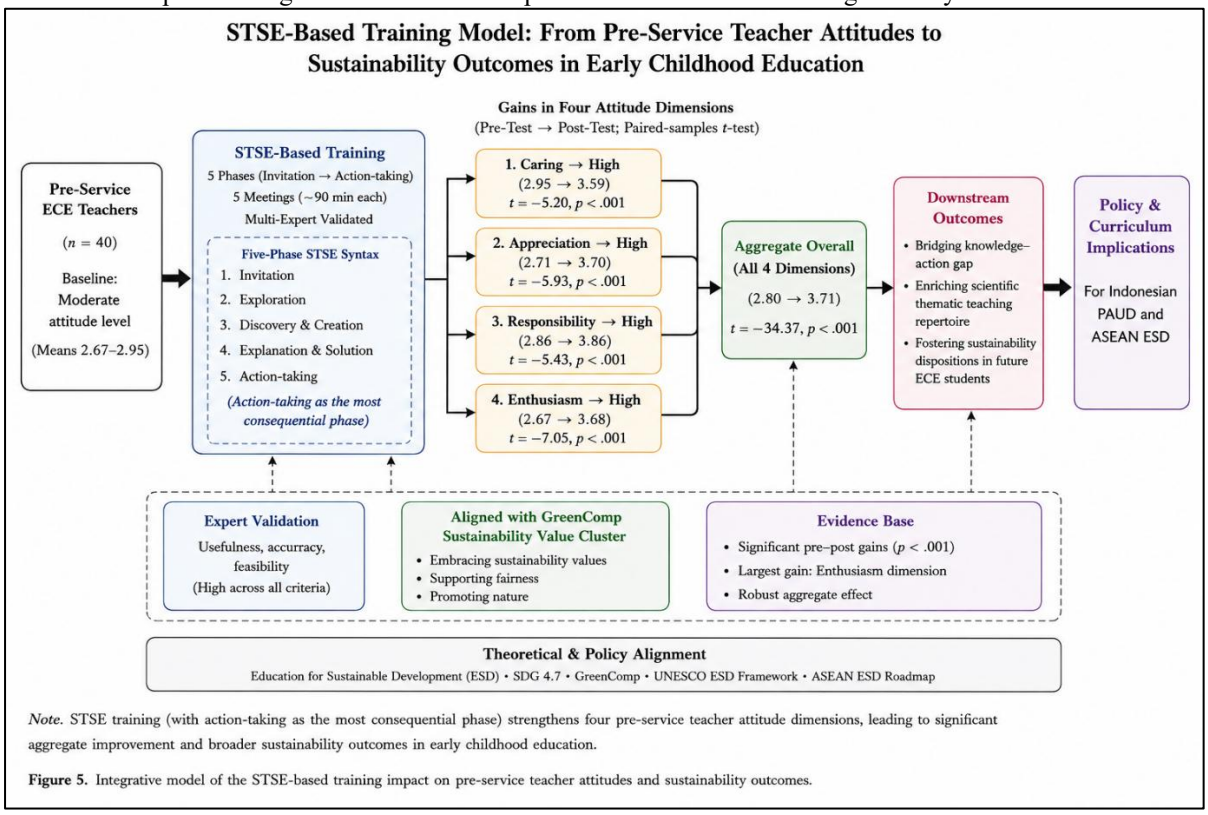


Figure 6. Integrated Conceptual Model Synthesising Findings and International Literature

6. Practical Implications

Some practical implications emerge for early childhood teacher education in Indonesia and similar contexts:

1. Curriculum integration. Given multiple documented "knowledge-affective-behaviour" gaps in Indonesian studies (Sulaeman et al., 2024).

2. Materials dissemination. The two-manual teaching resource may be used as a reusable training package for in-service training programmes, professional learning communities and continuing professional development among cascaded ECE teachers (for example, among practising ECE teachers where budget restrictions mean the time available each week within school curriculum activities for environmental education is limited) [14–15, 71].
3. Cross-institutional scaling. The model structure is validated by multiple experts according to the Delphi method, which makes our results likely adaptable and testable in other Indonesian universities or potentially at other Southeast Asian universities where similar gaps exist for environmental education (Rachman et al., 2024; Elmas et al., 2024; Phonnong et al., 2025).
4. Pedagogical model. Prioritising the action-taking phase in upcoming training rounds should furthermore be favoured, as it is the most distinctive component of the STSE architecture and meaningful for downstream pro-environmental behaviour (Crespo-Martín et al., 2025; Nascimento & Reis, 2025; Sourgiadaki & Karkalakos, 2023).
5. Policy leverage. The validated training package can serve as an evidence-based argument for faculty members responsible for ECE curriculum design while negotiating curricular hours for environmental education with faculty boards (Rachman et al., 2024; Alpusari et al., 2025).

7. Theoretical Implications

The research makes three key contributions to theory. First, it provides an empirical test of the extent to which the STSE model has cross-cultural mobility—a hypothesis often suggested but seldom substantiated (Bascopé et al., 2019; Rasis et al., 2023; Yıldırım & Sevi, 2016)—by extending this approach into the context of pre-service ECE teacher preparation in Indonesia. Second, the study connects STSE to behaviour-oriented, civic-oriented (backward-looking), and action-oriented (future-oriented) definitions of environmental citizenship (Nascimento & Reis, 2025; Spektor-Levy & Abramovich, 2016; Georgiou et al., 2021) by operationalising the five-phase model's syntax with a focus on taking action. Third, it adds to the literature on research and development methodologies in early childhood teacher education—which has been critiqued for sometimes prioritising effectiveness over expert triangulation (Yuyun et al., 2023a; Nawali et al., 2024; Siantoro et al., 2024)—by contributing multi-expert validation using a mixed-methods design combined with quantitative effectiveness testing.

8. Conclusion

This study investigates the development and validation of an STSE-based environmental education training model for Indonesian pre-service early childhood teachers through research and development processes. Based on seven of the ten Borg and Gall stages, a comprehensive training package was developed. This package consisted of a scenario manual, an appendix of supporting materials, and an associated website, all of which were validated by experts. The website, in particular, was rated by the expert panel as a highly useful, accurate, and feasible product. Forty pre-service teachers demonstrated statistically significant gains from pre-test to post-test on the four attitude dimensions and an aggregate score, with a large total effect observed across all measures. Therefore, training based on STSE represents a justifiable, replicable, and socially situated answer to the long-standing demand for the integration of ESD and environmental citizenship into teacher education from the earliest years. The model provides an international contribution to the literature on STSE in pre-service teacher education and a template for further adaptation and initial use.

9. Limitations

Several limitations should be acknowledged. (1) The study was a one-group pre-test–post-test without a parallel control group. Accordingly, it is impossible to definitively attribute the observed effects to STSE training alone, although quasi-experimental evidence from abroad indicates that a similarly structured coaching package yields analogous effects (Sidiropoulos, 2018; Khazen et al., 2025). Second, the sample is taken from one Indonesian university; thus, generalisability across institutional, regional, or cultural contexts is limited. Conducting greater replication across other institutions, as well as larger geographic regions, would enhance external validity. Third, the post-test conducted right after training prohibits any inference of long-term retention and behavioural transfer. Fourth, the voices of diverse stakeholders, including practicing ECE teachers, parents, and children themselves, were not captured in the validation phase, although three different domain experts were consulted. Fifth, the sub-aspect within the overall score of the instrument contained four items instead of five. Since the instrument is meant to reflect the four primary dimensions as parallel structures, this slight departure should be corrected in revised versions of the instrument.

10. Future Research

These results present a number of promising leads for future research. For example:
1. a randomized controlled trial—or at least quasi-experimental designs with matched comparison groups—needs to be conducted at several Indonesian universities and more widely in an Asian-Pacific context (Phonnong et al., 2025);
2. six- and twelve-month longitudinal follow-ups need to ascertain whether sustained pro-environmental behavior gains were similarly indicative of sustainable teaching practices, or merely reflected pedagogical beliefs or attitudes that do not translate into practice (Khazen et al., 2025); and
3. qualitative methodologies such as interviews, focus groups, and classroom observations should complement the quantification of changes in bias and attitudes—changes hypothesized to influence broader teaching practice.

These qualitative methods should also explore instances where learners' belief systems may have been further challenged regarding both climate change education and its curriculum design for ECE educators.
4.

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The authors would like to acknowledge the three experts from the domains of early childhood education, environmental education, and educational technology for their substantive evaluation of the developed training model, as well as 40 pre-service early childhood teacher candidates at Mataram University in Lombok who took part in its field test.

Conflict of Interest
The authors declare no conflict of interest.

Funding
The study was conducted with internal institutional funding allocated to the corresponding author's research programme at Mataram University.

Data Availability
The de-identified data supporting the findings of this study are available from the corresponding author on reasonable request, subject to ethical approval.

Appendix A. List of Abbreviations

Abbreviation	Full Term
CITC	Corrected Item–Total Correlation
ECE	Early Childhood Education
ECEs	Early Childhood Education settings
EE	Environmental Education
ESD	Education for Sustainable Development
GreenComp	European Sustainability Competence Framework
IBM SPSS	International Business Machines Statistical Package for the Social Sciences
KS Test	Kolmogorov–Smirnov Test
PAUD	Early Childhood Education (Pendidikan Anak Usia Dini, Indonesia)
R&D	Research and Development
SD	Standard Deviation
SDG	Sustainable Development Goal
SPSS	Statistical Package for the Social Sciences
STSE	Science–Technology–Society–Environment
UN	United Nations
UNESCO	United Nations Educational, Scientific and Cultural Organization

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